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(54) **Apparatus comprising Raman-active optical fiber.**

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OPTICS LETTERS, vol. 10, no. 8, August 1985,  
pages 420-422, Optical Society of America,  
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"Dependence of Raman gain on relative index  
difference for GeO<sub>2</sub>-doped single-mode  
fibers"**

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**Description****1. Field of the Invention**

5 This invention pertains to apparatus that comprises Raman-active optical fiber adapted for amplification of electromagnetic radiation by means of stimulated Raman scattering. Exemplarily, such apparatus can be an optical fiber communication system, an information processing system such as an optical computer, or an optical sensor system.

**10 Background of the Invention**

It has been known for some time that optical fibers can be advantageously used to amplify, by means of stimulated Raman scattering (SRS), radiation guided through the fiber. See, for instance, Optical Fiber Tele-  
communications, S. E. Miller and A. G. Chynoweth, editors, Academic Press, 1979, pages 127-133. Various  
 15 optical fiber communications systems that use Raman amplification of the signal have been proposed. An exemplary system is disclosed, for instance, in U. S. Patent 4,558,921.

Essentially all optical fiber used today for transmission purposes is silica-based fiber. Since silica, or silica lightly doped with other elements such as germanium, is known to have a non-zero Raman cross section, it is possible to use the normal transmission fiber also for amplification purposes, and systems of this type have  
 20 been proposed. See, for instance, L. F. Mollenauer et al, IEEE Journal of Quantum Electronics, Vol. QE-22(1), pages 157-173 (1986), and U. S. Patent 4,401,364.

Another approach to the design of an optical fiber communications system with Raman amplification is to use ordinary low-loss transmission fiber in conjunction with one or more lengths of Raman-active fiber that differ in composition from the low-loss transmission fiber. In this case, the signal amplification is not distributed  
 25 over essentially the whole length of the transmission path but is substantially localized in the Raman-active fiber sections. The Raman cross section of the Raman-active fiber typically is substantially larger than the Raman cross section of the low-loss transmission fiber. A convenient figure of merit for Raman-active fiber is the relative Raman cross section  $\sigma_r = \sigma_{RA}/\sigma_{SiO_2}$ , where  $\sigma_{RA}$  is the Raman cross section of the Raman-active fiber, and  $\sigma_{SiO_2}$  is the maximum Raman cross section of pure silica glass.

The prior art knows some Raman-active optical fibers whose  $\sigma_r$  is substantially greater than 1. For instance, E. Desurvire et al, Electronics Letters, Vol. 19(19), pages 751-753 (1983), report optical amplification of 1.24  $\mu$ m radiation in GeO<sub>2</sub>-SiO<sub>2</sub> single mode fiber. Since it is known that  $\sigma_r$  of pure GeO<sub>2</sub> is about 10, it is evident that the  $\sigma_r$  of GeO<sub>2</sub>-SiO<sub>2</sub> fiber will be less than 10. Use of GeO<sub>2</sub>-SiO<sub>2</sub> fibers or GeO<sub>2</sub> fibers is also taught in European Patent application 0146262.

35 C. Lin, Journal of optical Communications, Vol. 4(1), pages 2-9 (1983), discusses the design of optical fibers for, inter alia, optical amplification by SRS, and discloses that P<sub>2</sub>O<sub>5</sub> has a  $\sigma_r$  of about 5.

Japanese Patent 56-70683 discloses Raman-active optical fiber that comprises a SiO<sub>2</sub>-P<sub>2</sub>O<sub>5</sub>-GeO<sub>2</sub> glass core surrounded by a clad layer having the same constituents but lower refractive index, and Y. Durteste et al, Electronics Letters, Vol. 21(17), pages 723-724 (1985) report on Raman amplification in fluoride glass fibers.  
 40

Prior art Raman-active optical fiber typically has  $\sigma_r$  that is substantially less than 15. Thus, any optical fiber system that uses prior art Raman-active fiber to amplify the signal has to comprise relatively long lengths of the Raman-active fiber and/or use relatively high pump power levels. Having available Raman-active optical fiber having larger Raman cross section than prior art fiber would permit the use of shorter Raman amplifier sections and/or lower pump power levels, resulting in lower system cost and complexity. This application discloses high Raman cross section fiber, together with apparatus that comprises such fiber.

Various nonsilica-based glass systems have recently been investigated to determine their suitability in ultra low loss transmission fibers. Among these were glasses containing GeO<sub>2</sub> and heavy metal oxides such as Bi<sub>2</sub>O<sub>3</sub>, Ti<sub>2</sub>O, PbO, and Sb<sub>2</sub>O<sub>3</sub>. See, for instance, K. Nassau et al, Journal of the American Ceramic Society, vol. 65(10), pp. 486-491 (1982), and D. L. Wood et al, Applied Optics, Vol. 21(23), pp. 4276-4279 (1982). These investigations have led to the general conclusion that such heavy metal oxide glasses may have potential for low loss transmission waveguide fiber for the long wavelength region (e.g., 2-4  $\mu$ m) if ultra high purity glass can be prepared.

**55 Glossary and Definitions**

An "optical fiber" herein is an elongated dielectric body comprising a core and a cladding surrounding the

core, adapted for guiding electromagnetic radiation of a given wavelength  $\lambda_s$ , the "signal radiation". At least the core of the optical fiber consists of glass. At  $\lambda_s$  the effective refractive index of the core is greater than the cladding refractive index.

"stimulated Raman Scattering (SRS)" is a process that results in the transfer of energy from a "pump" radiation of wavelength  $\lambda_p$  to the signal radiation, thereby producing amplification of the signal. Typically  $\lambda_p < \lambda_s$ , with the frequency difference between signal and pump radiation referred to as the Stokes shift  $\Delta\nu$  (typically expressed in  $\text{cm}^{-1}$ ). The intensity of SRS in a given material, for a given pump intensity, Stokes shift and interaction length, is a function of the "Raman cross section"  $\sigma_{\text{RA}}(\Delta\nu)$  and of the temperature.

The "relative Raman cross section"  $\sigma_r(\Delta\nu)$  of a given material herein is the ratio of the 0°K Raman cross section of the material for the Stokes shift  $\Delta\nu$  to the maximum 0°K Raman cross section of vitreous  $\text{SiO}_2$ . The maximum in the  $\text{SiO}_2$  Raman cross section occurs at about  $\Delta\nu = 420 \text{ cm}^{-1}$ .

By "Raman-active" optical fiber we mean herein fiber having  $\sigma_r > 1$ . Typically such fiber has  $\sigma_r > 15$ .

#### Summary of the Invention

This invention embodies an apparatus that incorporates a high Raman cross section optical fiber adapted for amplification of optical radiation by means of stimulated Raman scattering. The apparatus may take various forms and embodiments, such as

a communications system that comprises the Raman-active optical fiber, an information processing system comprising optical fiber information storage means that comprises the Raman-active fiber or a measuring and/or sensing apparatus that comprises Raman amplification means, including the Raman-active fiber.

Apparatus according to the invention typically comprises a source of optical signal radiation, optical fiber forming a transmission path for the signal radiation from a first fiber location to a second fiber location, means for coupling the signal radiation into the fiber at the first fiber location, and signal radiation-responsive means at the second fiber location. Furthermore, such apparatus comprises Raman amplification means for the signal radiation, with the Raman amplification means comprising a length of Raman-active optical fiber that forms at least a part of the transmission channel for the signal radiation.

At least the core of the Raman-active optical fiber consists of glass comprising a glass-forming first major component and a heavy metal oxide second major component, the first and second major components together being at least about 70 mol%, preferably at least 90 mol%, of the core material (all compositional percentages herein are mol percent, unless stated otherwise). The first major component is chosen from the group consisting of  $\text{GeO}_2$ ,  $\text{SiO}_2$ ,  $\text{AsO}_{1.5}$ , and combinations thereof, and the second major component is selected from the group consisting of  $\text{PbO}$ ,  $\text{BiO}_{1.5}$ ,  $\text{SbO}_{1.5}$ ,  $\text{TiO}_{0.5}$ , and combinations thereof.

The above chemical formulae refer to the constituents of the glass. The starting materials used in the manufacture of the glass may, however, have different formulae. For example, the use of Ti in the form of  $\text{Ti}_2\text{O}_3$  starting material results in the presence of  $\text{TiO}_{0.5}$  in the melt and the glass formed therefrom. It is also to be noted that some compounds herein may be interchangeably referred to by their conventional formula (e.g.,  $\text{Bi}_2\text{O}_3$ ) and by their equivalent single cation formula (e.g.,  $\text{BiO}_{1.5}$ ).

The relative Raman cross section for the signal radiation in the Raman-active optical fiber used in the invention is at least about 15, and preferably is greater than 20. Typically, the first major component is between about 25 and about 60% of the core of the fiber.

In preferred embodiments, the Raman-active optical fiber also comprises a glass cladding, with the cladding material also comprising the first and second major components, which together make up at least about 70%, preferably at least 90%, of the cladding. The core and cladding compositions are selected such that the effective refractive index of the core is greater than that of the cladding by a predetermined amount. Frequently, the first and second major components make up substantially all of the core material and of the cladding material.

In two exemplary preferred embodiments, the average composition of the core material is about  $40\text{GeO}_2$   $30\text{BiO}_{1.5}$   $30\text{PbO}$  and  $60\text{GeO}_2$   $40\text{SbO}_{1.5}$ , respectively. The numerical factors are understood to be mol percent. Currently preferred compositional ranges in the  $\text{GeO}_2$ - $\text{BiO}_{1.5}$ - $\text{PbO}$  system and the  $\text{GeO}_2$ - $\text{SbO}_{1.5}$ - $\text{BiO}_{1.5}$  system are depicted in FIGS. 1 and 2, respectively.

Substitution of  $\text{SiO}_2$  for some or all of  $\text{GeO}_2$  generally results in a decrease of the Raman cross section of the fiber. On the other hand, the addition of  $\text{SiO}_2$  results in a more viscous melt, which in turn makes for easier fiber drawing and reduces the likelihood of crystallization. We currently consider that the amount of  $\text{SiO}_2$  present in the core of the inventive fiber should not exceed 50% of the core material, and preferably not exceed 50% of the first major component in the core.

A preferred use of the Raman-active optical fiber is in optical fiber telecommunications systems. In such systems, the inventive fiber can, for instance, be incorporated into the long haul trunk portion of the system,

to compensate for signal attenuation due to loss in the fiber. It can also be used in the distribution and/or customer loop portion to compensate for, inter alia, signal loss due to taps that divert signal energy into side branches of the network and/or into subscriber stations. Use of the fiber is also envisaged in local area networks and other private networks.

The Raman-active fiber also can advantageously be used in information processing apparatus in which the signal is, during at least part of the processing thereof, in optical form. If such apparatus comprises an optical fiber transient memory loop, then the fiber advantageously is incorporated into the optical fiber loop such as to compensate for signal attenuation in the loop.

Fiber used in the invention also can be advantageously used in optical fiber sensing and/or measuring apparatus. Exemplary of such apparatus are optical fiber rotation sensors, accelerometers, thermometers, strain sensors, pressure sensors, pollution detectors, and magnetometers.

#### Brief Description of the Drawings

FIG. 1 shows the compositional diagram of the  $\text{GeO}_2\text{-BiO}_{1.5}\text{-PbO}$  system, outlining a composition regime useful in the practice of the invention;

FIG. 2 similarly shows the compositional diagram of the  $\text{GeO}_2\text{-SbO}_{1.5}\text{-BiO}_{1.5}$  system;

FIGS. 3 and 4 show the relative Raman cross sections, as a function of Stokes frequency shift, of two preferred exemplary glass compositions;

FIG. 5 exemplifies the effect of the substitution of  $\text{SiO}_2$  for  $\text{GeO}_2$  on the Raman cross section in Raman-active glass;

FIG. 6 schematically depicts an optical fiber telecommunications system with Raman amplification;

FIG. 7 schematically depicts a further optical fiber communications system with Raman amplification, namely, a ring-configured local area network; and

FIG. 8 schematically shows information processing apparatus that comprises an optical fiber information storage loop with Raman amplification.

#### Detailed Description

A central aspect of this invention is the provision of optical fiber having a relatively large  $\sigma_r$  of typically at least about 15, and preferably as large as 20 or even 30. The fibers comprise glass not previously known to have large Raman cross section, and thus to have advantageous uses in Raman amplification of electromagnetic radiation.

#### The Fiber

Glasses used in the invention have two major components, the first being a glass-former component ( $\text{GeO}_2$ ,  $\text{SiO}_2$ ,  $\text{AsO}_{1.5}$ , or combinations thereof), the second being a heavy metal oxide component ( $\text{PbO}$ ,  $\text{BiO}_{1.5}$ ,  $\text{SbO}_{1.5}$ ,  $\text{TlO}_{0.5}$ , or combinations thereof). The two major components together account for at least 70%, preferably at least 90%, of the Raman-active fiber core, frequently making up substantially all of the core, or all of the fiber.

FIG. 1 shows the phase diagram of an exemplary ternary system, the  $\text{GeO}_2\text{-BiO}_{1.5}\text{-PbO}$  system. Line 10 is the boundary of the glass-forming region 13, and lines 11 (ABCD) and 12 enclose those compositions for which the relative Raman cross section is at least about 20 and 30, respectively. The relative Raman cross sections at a, b, c, and d are 36, 27, 16, and 15, respectively. Point a corresponds approximately to the composition with highest relative Raman cross section in this particular ternary system.

FIG. 2 depicts a similar phase diagram for the  $\text{GeO}_2\text{-SbO}_{1.5}\text{-BiO}_{1.5}$  system. Line 20 (GHI) is the boundary of the glass-forming region 21, and line 22 (EFG) is the  $\sigma_r \sim 20$  contour. Line 23 is the  $\sigma_r \sim 25$  contour, and points a, b, c, d, and e are compositions having  $\sigma_r$  of 30, 27, 24, 21, and 18, respectively.

Typically, replacement of some  $\text{GeO}_2$  by  $\text{SiO}_2$  results in somewhat lower  $\sigma_r$ . For instance, for compositions according to FIG. 2 but with 10%  $\text{SiO}_2$  replacing 10%  $\text{GeO}_2$ , the  $\sigma_r$  at point b is 22, and at the intersection of line 22 with the zero- $\text{BiO}_{1.5}$  (point E) axis  $\sigma_r$  is 17.

The  $\text{GeO}_2\text{-BiO}_{1.5}\text{-PbO}$  and  $\text{GeO}_2\text{-SbO}_{1.5}\text{-BiO}_{1.5}$  systems (with or without  $\text{SiO}_2$  replacing some of the  $\text{GeO}_2$ ) are examples of glasses having only one dominant peak in the Raman spectrum. Such glasses are currently preferred by us. However, for some applications it may be advantageous to use a glass having two or more strong Raman peaks, and in such cases members of other glass systems may be preferred.

FIGS. 3 and 4 show the Raman spectra of two exemplary Raman-active glasses used in the invention. As can be seen, glass of composition 40 $\text{GeO}_2$  30 $\text{BiO}_{1.5}$  30 $\text{PbO}$  has maximum  $\sigma_r$  at a Stokes shift of about 140

cm<sup>-1</sup>, whereas in 60GeO<sub>2</sub> 40SbO<sub>1.5</sub> glass the maximum occurs at about 420 cm<sup>-1</sup>.

FIG. 5 further illustrates the effect of GeO<sub>2</sub>/SiO<sub>2</sub> substitution, for glasses of composition xSiO<sub>2</sub> (40-x)GeO<sub>2</sub> 30BiO<sub>1.5</sub> 30PbO. The relative Raman cross section at 140 cm<sup>-1</sup> frequency shift decreases from about 36 for x=0 to about 27 at x=40%. However, since addition of SiO<sub>2</sub> typically results in improved processing characteristics of the glass, it may frequently be found desirable to use SiO<sub>2</sub>-containing glass.

Fiber used in the invention can be produced by any appropriate method, e.g., by melting of the constituents in an inert vessel such as a platinum crucible, and drawing of fiber directly from one or more orifices in the crucible. Although typically the fiber comprises both a glass core and a glass cladding surrounding the core, the invention can also be practiced with optical fiber that has a glass core and a non-glass (e.g., polymer) cladding. An advantageous known method for producing the former type is by means of the double crucible method. However, it is also possible to use other techniques, e.g., to draw the fiber from a preform that was produced by casting of the molten glass into an appropriate mold. Glass preparation, fiber drawing, and possibly other high temperature manufacturing steps may be carried out in air, other oxygen containing gases, or in an appropriate inert gas (e.g., N<sub>2</sub>, He) atmosphere, depending on, inter alia, the particular constituents used.

Fiber used in the invention can have any desired refractive index profile, including step index and graded index, can have one or more cladding layers, be single mode or multimode, and be incorporated into any appropriate single or multi-fiber cable. If the fiber has both a glass core and cladding then typically both core and cladding contain the same constituents adjusted such as to result in the desired difference between the effective refractive index of the core and of the cladding. However, if desired, e.g., to achieve equality of thermal expansion between core and cladding material, it is possible to add to the core or the cladding a constituent that is not present in the cladding or the core, respectively. Furthermore, it is envisaged that minor amounts (a total of at most 30, preferably < 10%) of constituents other than the two previously referred to major components may be present in the fiber. Typically no individual minor constituent is present in an amount > 15 or 10%. Such minor constituents might be added to improve, for instance, the processability, mechanical properties, or stability (including radiation resistance) of the glass, or of the fiber produced therefrom.

#### Example 1

Raman-active step index optical fiber is produced by preparing, in a platinum double crucible, a well mixed core melt of composition 30GeO<sub>2</sub> 10SiO<sub>2</sub> 30PbO 30BiO<sub>1.5</sub>, and a well mixed cladding melt of composition 27GeO<sub>2</sub> 13SiO<sub>2</sub> 30PbO 30BiO<sub>1.5</sub>. After melt formation the double crucible is allowed to cool to about 500°C and maintained at that temperature in an air atmosphere. Fiber is drawn from the double orifice of the double crucible and, after solidification and cool-down, coated with a polymer. The fiber has an outer diameter of about 125 μm, a core size of about 8 μm, a cladding refractive index of about 2.0, and a core/cladding index difference of about 1%. The optical fiber has σ<sub>r</sub> ~ % 32 at the signal radiation wavelength 1.550 μm, with pump radiation of wavelength 1.517 μm (140 cm<sup>-1</sup> Stokes shift).

#### Examples 2-12

Table I summarizes the glass compositions and results of the Raman measurements of Examples 2-12. Listed are the mol percent of the various glass constituents, and (in addition to the maximum σ<sub>r</sub>, the Stokes shift (in cm<sup>-1</sup>) at which the Raman cross section is a maximum.

The glasses of Examples 2-12 were prepared by ball milling of the constituents, melting the constituents in platinum crucibles in air at about 1100°C, and pouring of the melt into a stainless steel mold. The resulting glass samples were then annealed for one hour at or near the glass transition temperature, cooled at 1°C/min to room temperature, cut, polished, and the Raman spectrum measured by conventional means.

Whereas many of the glass compositions of Examples 2-12 have more than one strong Raman peak, the glasses of Examples 9, 10, 11 and 12 show only one strong Raman peak. For instance, the glass of Example 5 has two strong peaks, with the second strongest occurring at Δν = 150 cm<sup>-1</sup> and having σ<sub>r</sub> = 21.

Table 1

Example	GeO <sub>2</sub>	SiO <sub>2</sub>	AsO <sub>1.5</sub>	BiO <sub>1.5</sub>	PbO	SbO <sub>1.5</sub>	TlO <sub>0.5</sub>	$\sigma_z$	$\Delta V$
2	60			40				23	410
3	60						40	31	40
4	50			25	25			20	140
5	40			30		30		24	410
6	40			30			30	30	450
7	40				30	30		17	100
8	40				30		30	27	90
9	40			20	20		20	30	140
10		40		30	30			27	140
11			50			50		28	420
12	48					52		30	420

### The Apparatus

Raman-active fiber used in the invention can advantageously be used whenever efficient Raman amplification of optical fiber-guided signal radiation (typically in the range 0.5  $\mu\text{m}$  to 4.0  $\mu\text{m}$ ) is required. FIG. 6 schematically depicts exemplary apparatus that uses such fiber in Raman amplification means, namely, an optical

fiber communications system which uses Raman amplification to compensate for the signal attenuation in the transmission path. Signal source 62 (e.g., a semiconductor laser) can be modulated by means of input signal 61. Signal radiation 63 is coupled by means that are not shown (e.g., a lens) into optical transmission fiber 641 (e.g., conventional SiO<sub>2</sub>-based low loss single mode fiber) that is part of an optical fiber transmission path from the signal source to detector 66, which receives signal radiation 63 and provides an output signal 65.

At least at one intermediate location a length of Raman-active fiber 642 is inserted into the transmission path and coupled to the transmission fibers 641 by any appropriate coupling means 67. Such means are well known in the art and require no discussion. Pump source 68 emits pump radiation 69 which is coupled into the Raman-active fiber by known means that are also not shown.

The pump source can be a single source or it can comprise a battery of sources, e.g., light emitting diodes. The pump radiation can be cw or pulsed, is of shorter wavelength than the signal radiation by an amount that typically corresponds substantially to the Stokes shift that results in maximum Raman scattering, and can be coupled into 642 so as to be co- and/or counter-propagating with the signal radiation. Furthermore, at least in some cases it may be advantageous to provide means for selectively removing pump radiation from the transmission path, to prevent accumulation of pump frequency background radiation. In some long haul communication systems of the type depicted in FIG. 6, it may be desirable to provide, at appropriate intervals along the transmission path, means for reshaping of the signal pulses to prevent excessive pulse spreading. Such means, for instance, can be repeaters of the type currently used in optical fiber transmission systems. All these considerations are well known to those skilled in the art.

FIG. 7 shows schematically a second exemplary optical fiber communications system according to an embodiment of the invention, namely, a ring-configured local area network 70 that uses Raman amplification to, inter alia, compensate for signal attenuation due to the presence of a multiplicity of taps. The ring transmission path comprises conventional transmission fiber 641 and at least one length of Raman-active fiber 642, coupled to 641 by conventional coupling means 67. A multiplicity of terminals 71 are coupled to the transmission fiber by known means 72, typically taps that permit coupling-in as well as coupling-out of signal radiation. A source 68 of Raman pump radiation is coupled to the Raman-active fiber by known means (not shown). Arrows in FIG. 7 indicate that the pump and signal radiation 63 are counter-propagating; this is exemplary only. It will be understood that a local area network may, if so desired, comprise a connection to the public switched network, or to other private networks. This is indicated by means of the optionally present interface unit 73.

FIG. 8 schematically illustrates a further exemplary embodiment of the invention, namely, an information processing system 80 with an optical fiber (transient) memory with Raman amplification. Exemplary of such a system is an optical digital computer, or a hybrid (electronic-optical) digital computer. FIG. 8 shows input device 81 providing signals 82 to processing unit 83, which in turn provides signals 84 to output device 85. Coupled to 83 is an optical fiber memory loop, typically comprising transmission fiber 641, as well as comprising at least one length of Raman-active optical fiber 642, coupled together by conventional means 67. Pump radiation source 68 provides pump radiation 69 that is coupled into 642 by known means (not shown). Signal pulses 87 are coupled into the fiber loop by known coupling means 72, circulate one or more times around the loop, are coupled out by similar coupling means 72 and provided to the processing unit 83. Raman amplification of re-circulating pulses in a re-entrant fiber loop is disclosed in E. Desurvire et al, Optics Letters, Vol. 10(2), pp. 83-85 (1985).

Those skilled in the art will recognize that the inventive apparatus can also be used in a variety of other apparatus, and all such uses are contemplated. Exemplary of such other apparatus are optical fiber sensors, e.g., rotation sensors, accelerometers, strain sensors, thermometers, pressure sensors, magnetometers, and pollution sensors.

## Claims

### 1. Apparatus comprising

- a source (62) optical signal radiation (63),
- optical fiber mean (641) forming a transmission path for the signal radiation from a first fiber location to a second fiber location;
- means for coupling the signal radiation into the fiber at the first fiber location, and signal radiation-responsive means (66) at the second fiber location; and
- signal radiation Raman amplification means (642) that comprising a length of a Raman-active optical fiber (642) that forms at least part of the transmission path for the signal radiation, the Raman-active optical fiber comprising a core and a cladding surrounding the core;

CHARACTERIZED IN THAT

at least the core of the Raman-active optical fiber consists of glass comprising a glass-forming first major component selected from  $\text{GeO}_2$ ,  $\text{SiO}_2$ ,  $\text{AsO}_{1.5}$ , and combinations thereof; and a heavy metal oxide second major component selected from  $\text{PbO}$ ,  $\text{BiO}_{1.5}$ ,  $\text{SbO}_{1.5}$ ,  $\text{TiO}_{0.5}$ , and combinations thereof;

5 the first and second major components together are at least 70 mol% of at least the core, and the relative Raman cross section for the signal radiation in the Raman-active optical fiber is at least 15.

2. Apparatus according to claim 1,  
10 CHARACTERIZED IN THAT the first major component is between about 25 and about 60 mol% of at least the core.
3. Apparatus according to claim 2,  
CHARACTERIZED IN THAT  
15 the second major component consists essentially of  $\text{BiO}_{1.5}$  and  $\text{PbO}$ , or of  $\text{SbO}_{1.5}$  or of  $\text{SbO}_{1.5}$  and  $\text{BiO}_{1.5}$ .
4. Apparatus according to claim 1 or 2,  
CHARACTERIZED IN THAT  
20  $\text{SiO}_2$  is at most 50 mol% of at least the core.
5. Apparatus according to claim 1,  
CHARACTERIZED IN THAT the cladding consists of glass comprising the first and second major components, with the first and second major components being at least 70 mol% of the cladding.
- 25 6. Apparatus according to any one of preceding claims 1-5,  
CHARACTERIZED IN THAT the apparatus is an optical fiber communications system (60, 70).
7. Apparatus according to any one of preceding claims 1-5,  
30 CHARACTERIZED IN THAT the apparatus is an information processing system (80) comprising optical fiber signal storage means comprising a closed loop optical fiber transmission path (641, 642), with the signal radiation-responsive means being means (72) for coupling out of the fiber at least a portion of the signal radiation.
- 35 8. Apparatus according to claim 7,  
CHARACTERIZED IN THAT the information processing apparatus is a digital computer.
9. Apparatus according to claim 1,  
40 CHARACTERIZED IN THAT the apparatus is an optical fiber sensor.
10. Apparatus according to claim 9,  
CHARACTERIZED IN THAT  
45 the optical fiber sensor is a rotation sensor, an accelerometer, a strain sensor, a thermometer, a magnetometer, a pressure sensor, or a pollution sensor.

#### Patentansprüche

- 50 1. Einrichtung mit folgenden Merkmalen:  
eine Quelle (62) von optischer Signalstrahlung (63), eine optische Fasereinrichtung (641), die einen Übertragungsweg für die Signalstrahlung von einer ersten Faserstelle zu einer zweiten Faserstelle bildet;  
eine Kopplungseinrichtung für die Signalstrahlung in die Faser an der ersten Faserstelle und eine auf die  
55 Signalstrahlung ansprechende Einrichtung (66) an der zweiten Faserstelle;  
eine Raman-Signalstrahlung-Verstärkungseinrichtung mit einer Länge einer Raman-aktiven optischen Faser (642), die mindestens einen Teil des Übertragungswegs für die Signalstrahlung bildet, wobei die Raman-aktive optische Faser einen Kern und eine den Kern umgebende Beschichtung aufweist,



dadurch gekennzeichnet,  
daß mindestens die Raman-aktive optische Faser aus Glas folgender Zusammensetzung besteht:

5 ein glasbildender erster Hauptbestandteil, ausgewählt aus  $\text{GeO}_2$ ,  $\text{SiO}_2$ ,  $\text{AsO}_{1,5}$  und Kombinationen der Bestandteile, und ein Schwermetalloxid enthaltender, zweiter Hauptbestandteil, ausgewählt aus  $\text{PbO}$ ,  $\text{BiO}_{1,5}$ ,  $\text{SbO}_{1,5}$ ,  $\text{TiO}_{0,5}$  und Kombinationen dieser Bestandteile;  
daß die ersten und zweiten Hauptbestandteile zusammen mindestens 70 Mol.% von mindestens dem Kern ausmachen und daß der relative Raman-Querschnitt für die Signalstrahlung in der Raman-aktiven optischen Faser mindestens 15 beträgt.

10 2. Einrichtung gemäß Anspruch 1,  
dadurch gekennzeichnet, daß der erste Hauptbestandteil zwischen ungefähr 25 und ungefähr 60 Mol.% von mindestens dem Kern beträgt.

15 3. Einrichtung nach Anspruch 2,  
dadurch gekennzeichnet, daß der zweite Hauptbestandteil im wesentlichen aus  $\text{BiO}_{1,5}$  und  $\text{PbO}$ , oder aus  $\text{SbO}_{1,5}$  oder aus  $\text{SbO}_{1,5}$  und  $\text{BiO}_{1,5}$  besteht.

20 4. Einrichtung nach Anspruch 1 oder 2,  
dadurch gekennzeichnet, daß  $\text{SiO}_2$  höchstens 50 Mol.% von mindestens dem Kern beträgt.

25 5. Einrichtung nach Anspruch 1,  
dadurch gekennzeichnet, daß die Beschichtung aus Glas mit den ersten und zweiten Hauptbestandteilen besteht, wobei die ersten und zweiten Hauptbestandteile mindestens 70 Mol.% der Beschichtung ausmachen.

6. Einrichtung nach einem der Ansprüche 1 bis 5,  
dadurch gekennzeichnet, daß die Einrichtung ein optisches Faserübertragungssystem (60, 70) darstellt.

30 7. Einrichtung nach einem der Ansprüche 1 bis 5,  
dadurch gekennzeichnet, daß die Einrichtung ein Informationsverarbeitungssystem (80) darstellt, das eine Signalspeichereinrichtung mit optischer Faser und mit einem optischen Faserübertragungsweg (64, 642) in geschlossener Schleife umfaßt, wobei die auf die Signalstrahlung ansprechende Einrichtung eine Einrichtung (72) zum Auskoppeln mindestens eines Teils der Signalstrahlung aus der Faser aufweist.

35 8. Einrichtung nach Anspruch 7,  
dadurch gekennzeichnet, daß die Informationsverarbeitungseinrichtung ein digitaler Computer ist.

9. Einrichtung nach Anspruch 1,  
dadurch gekennzeichnet, daß die Einrichtung einen optischen Fasersensor darstellt.

40 10. Einrichtung nach Anspruch 9,  
dadurch gekennzeichnet, daß der optische Fasersensor einen Rotationssensor, einen Dehnungssensor, ein Thermometer, ein Magnetometer, einen Drucksensor oder einen Umweltverschmutzungssensor darstellt.

## Revendications

1. Appareil comprenant  
50 une source (62) de rayonnement (63) de signaux optiques;  
un moyen à fibre optique (641) qui forme pour le rayonnement de signaux un trajet de transmission d'un premier emplacement de fibre à un deuxième emplacement de fibre;  
un moyen de couplage du rayonnement de signaux dans la fibre au premier emplacement de fibre, et un moyen qui répond (66) au rayonnement de signaux au deuxième emplacement de fibre; et  
55 un moyen d'amplification de Raman de rayonnement de signaux comprenant une longueur de fibre optique à effet Raman (642) qui forme au moins une partie du trajet de transmission du rayonnement de signaux, la fibre optique à effet Raman comprenant un noyau et un gainage entourant le noyau;  
caractérisé en ce qu'il

au moins le noyau de la fibre optique à effet Raman est un verre comprenant:  
un premier composant majeur de formation de verre choisi parmi  $\text{GeO}_2$ ,  $\text{SiO}_2$ ,  $\text{AsO}_{1,5}$  et des combinaisons de ceux-ci; et un deuxième composant majeur d'oxyde d'un métal lourd, choisi parmi  $\text{PbO}$ ,  $\text{BiO}_{1,5}$ ,  $\text{SbO}_{1,5}$ ,  $\text{TlO}_{0,5}$  et des combinaisons de ceux-ci;

5 le premier et le deuxième composants majeurs constituent au moins 70% en pourcentage molaire du noyau, et

la section transversale relative de Raman pour le rayonnement de signaux dans la fibre optique à effet Raman est d'au moins 15.

10 2. Appareil selon la revendication 1, caractérisé en ce que le premier composant majeur représente entre environ 25 et environ 60% en pourcentage molaire du noyau.

15 3. Appareil selon la revendication 2, caractérisé en ce que le deuxième composant majeur consiste essentiellement en  $\text{BiO}_{1,5}$  et  $\text{PbO}$  ou en  $\text{SbO}_{1,5}$  ou en  $\text{SbO}_{1,5}$  et  $\text{BiO}_{1,5}$ .

20 4. Appareil selon la revendication 1 ou 2, caractérisé en ce que  $\text{SiO}_2$  représente au plus 50% en pourcentage molaire du noyau.

25 5. Appareil selon la revendication 1, caractérisé en ce que le gainage est en verre comprenant le premier et le deuxième composants majeurs, le premier et le deuxième composants majeurs représentant au moins 70% en pourcentage molaire du gainage.

30 6. Appareil selon l'une quelconque des revendications 1 à 5, caractérisé en ce que l'appareil est un système de communication (60, 70) à fibres optiques.

35 7. Appareil selon l'une quelconque des revendications 1 à 5, caractérisé en ce que l'appareil est un système de traitement (80) d'information comprenant un moyen de mémorisation de signaux à fibre optique comprenant un trajet de transmission (641, 642) à fibre optique en boucle fermée, le moyen qui répond au rayonnement de signaux étant un moyen (72) qui sert à coupler hors de la fibre au moins une partie du rayonnement de signaux.

40 8. Appareil selon la revendication 7, caractérisé en ce que le moyen de traitement d'information est un ordinateur numérique.

45 9. Appareil selon la revendication 1, caractérisé en ce que l'appareil est un capteur à fibre optique.

50 10. Appareil selon la revendication 9, caractérisé en ce que le capteur à fibre optique est un capteur de rotation, un accéléromètre, un capteur de déformation, un thermomètre, un magnétomètre, un capteur de pression, ou un capteur de pollution.

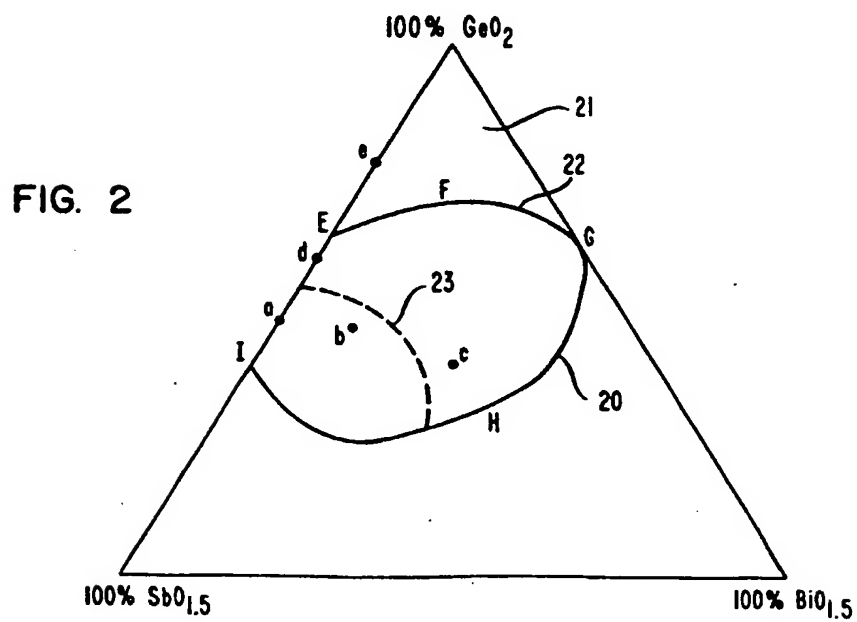
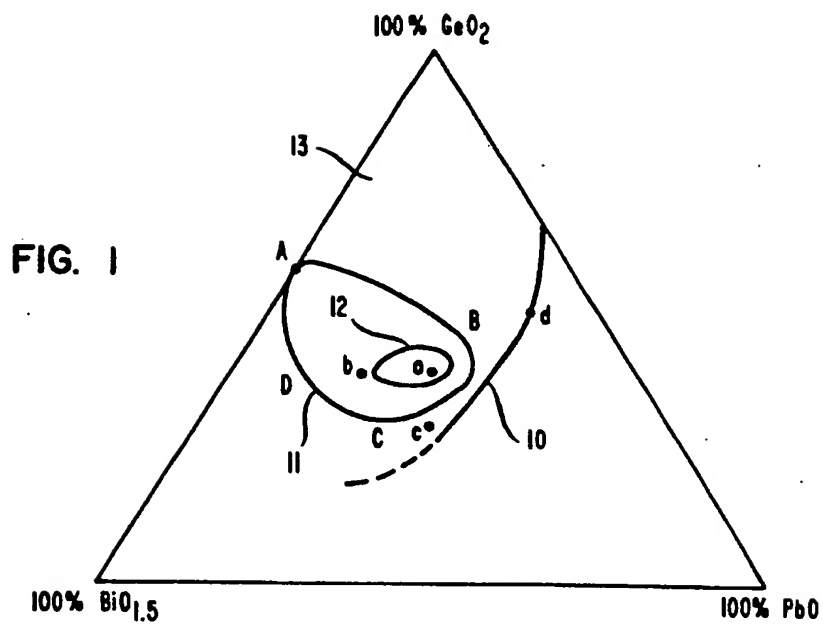


FIG. 3

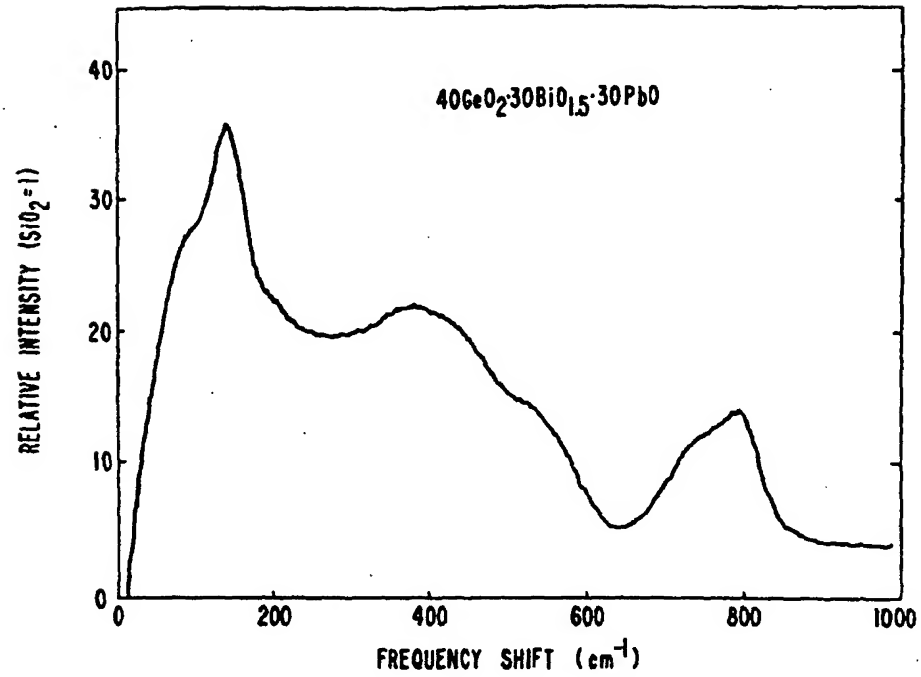
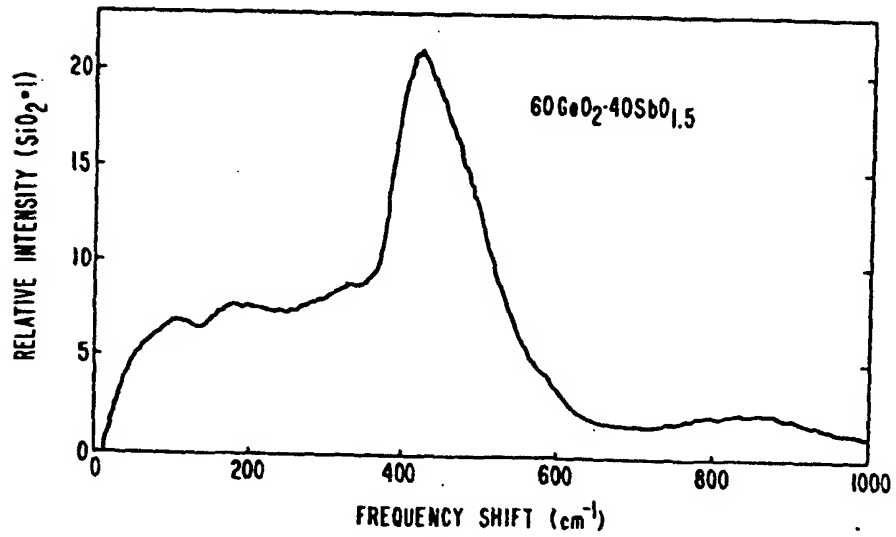


FIG. 4



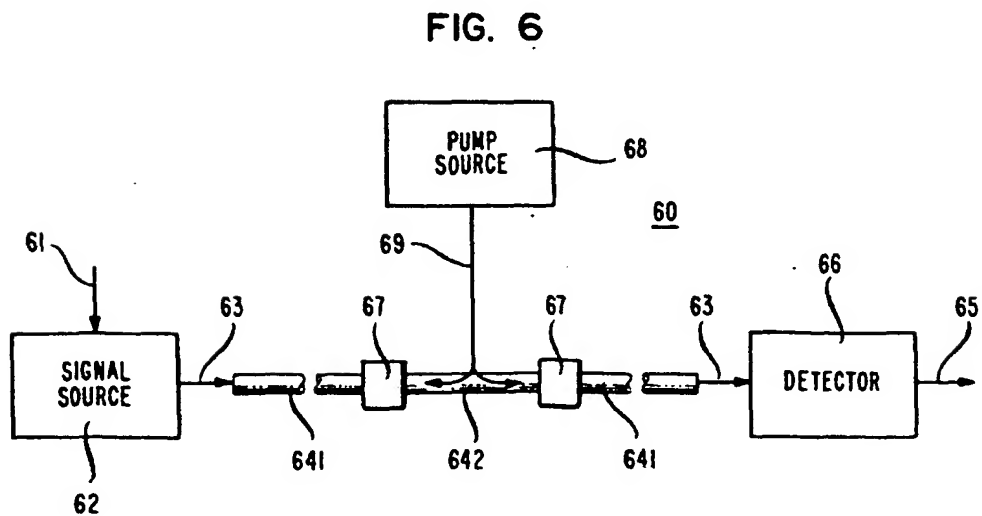
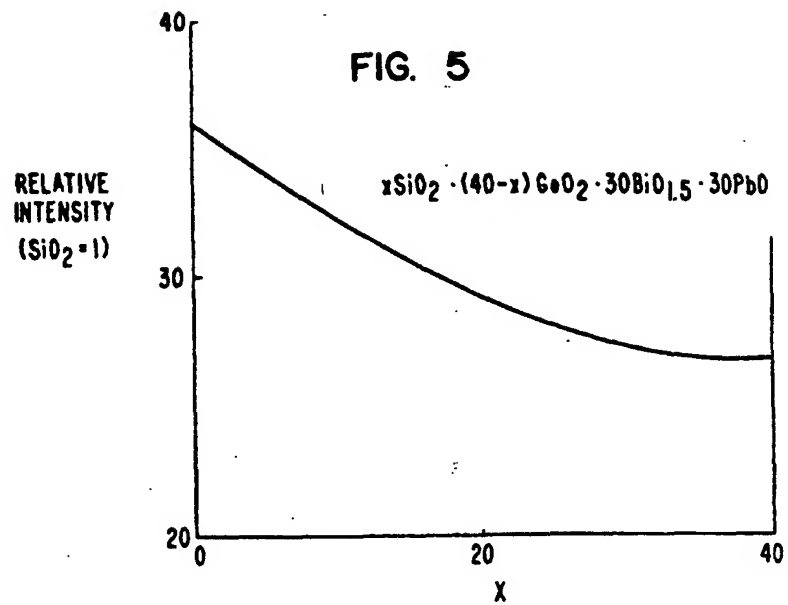


FIG. 7

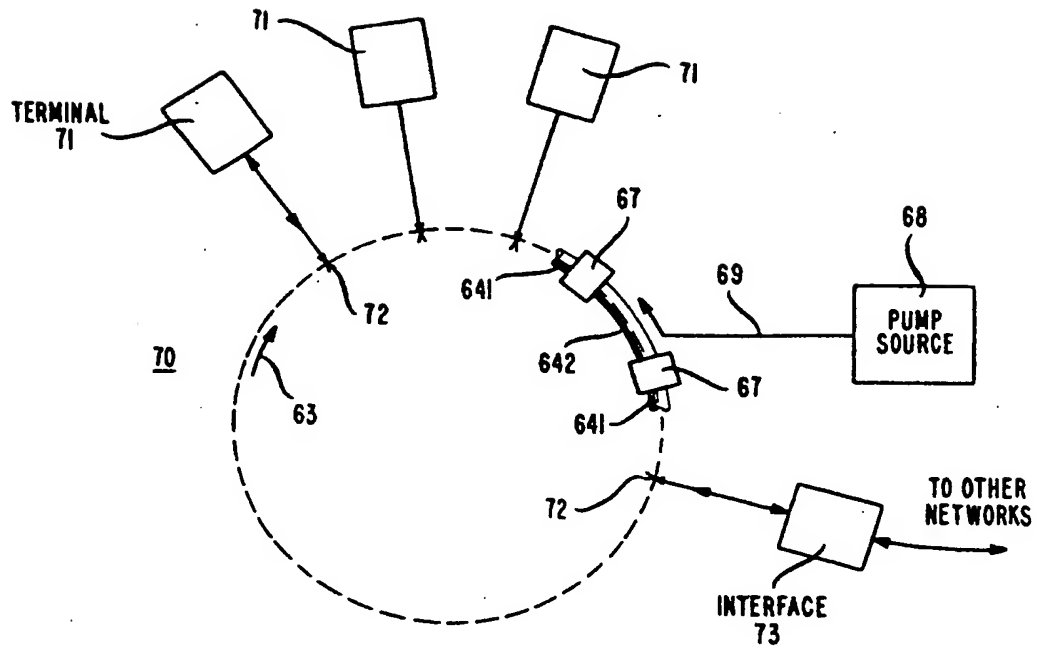


FIG. 8

